Ice Displacement Vectors Measured in the Northern Bering Sea

by

William J. Stringer

and

Richard D. Henzler

Geophysical Institute

University of Alaska

Fairbanks, Alaska

December 20, 1982

NOAA-OCS Contract No. 81-RA00147

Research Unit 267

Ice Displacement Vectors Measured in the Northern Bering Sea

by

William J. Stringer

and

Richard D. Henzler

Geophysical Institute

University of Alaska

Fairbanks, Alaska

December 20, 1982

NOAA-OCS Contract No. 81-RA00147

Research Unit 267

Ice Displacement Vectors Measured in the Northern Bering Sea

Introduction

The material in this report has been prepared to aid in assessment of environmental impact occurring as a result of offshore petroleum development in the U.S. portion of the northern Bering Sea. The principal product of this work is a series of maps showing daily ice floe vector displacements. The chief reason for their preparation (at the original scale of 1:500,000) was to give oceanographic modelers case studies against which to test models including a layer of ice placed on top of an oceanographic model. This report contains greatly reduced copies of those maps and has been prepared to provide other OCSEAP investigators and authors of environmental impact statements with these comprehensive views of ice movement vector fields in the northern Bering Sea. A detailed analysis of these vector fields would be quite involved and has not yet been performed. However, it was possible to group the movement patterns in such a way as to define modes of ice movement patterns within the study area and draw a few other conclusions as well.

Data

The maps of ice floe vector fields contained here were compiled by means of superimposition of Landsat imagery. This is possible at arctic latitudes because Landsat is a polar-orbiting satellite with orbits designed to provide a 10% overlap between adjacent images taken one day apart at the equator. The orbit paths must converge with increasing latitude and as a consequence, a given location at the latitude of this study area will be imaged on three successive days. Hence, it is at least theoretically possible that trajectories representing up to 48 hours of motion may be recorded. In addition, since successive satellite orbit paths move westward, it was occasionally possible to monitor a westward-traveling floe for 72 hours.

Obviously, the determination of floe trajectories depends not only on the acquisition of reasonably cloud-free imagery, but also on the ability to recognize specific floes from one image to the next. It is possible that satisfying the first requirement might possibly cause a significantly skewed selection of data. As a result of this, careful testing must be done before performing statistical analyses on results from this data set. However, it should be possible to group the data in order to identify modes of ice movement. (Even here it is possible that a strong link between cloudiness and mode might totally eliminate observations of a particular mode.)

Satisfaction of the floe identification requirement could be expected to limit observations at times when floes were-undergoing destruction or being compacted to such a degree, that floe boundaries were no longer recognizable. This potential problem did not impose a serious limitation to the compilation of a comprehensive data set, although it was apparent from time to time.

The displacements reported here were measured by sequentially projecting successive Landsat multispectral (MSS) images on a transparent screen so that individual pieces of ice could be tracked. (The device used is called a "color-additive viewer" and is manufactured by I^2S, Inc.) The Landsat images were projected to 1:500,000 scale from 70 mm positive transparencies. Registration of images was provided by superimposing geographical features on the sequential Landsat images. Colvocoresses and McEwen (1973) have shown that the random distortions on a Landsat MSS image have a root mean square value on the order of 200 m. This is the average error to be expected from the instrumentation. However, the results reported here were based on a visual best fit of two projected images. At the scale used, 1:500,000, 1 km is 2 mm. Some transparencies appeared to superimpose uniformly over the whole Landsat image to well within 1 mm (500m) while others would show apparent displacements of geographical features of 2 km on one side of a pair of images made to coincide on the opposite side. In these latter cases, a best average fit was obtained. Since the geographical features used are located at the top, both sides and in the center of the study area, this technique tended to minimize the errors in the center of the area of observation. The errors resulting from this latter systematic effect are estimated to be on the order of 1 km. Even though this latter error would be systematic, it would not be easy to describe and correct. Therefore, the uncertainty placed on the daily floe displacement reported here has been placed at 1 km.

Observations

The following observations are made based on a first-cut examination of the data set just presented. More detailed analyses are anticipated in the future.

1. Modes of ice movement.

Based on observations by many authors (Muench and Ahlnas, 1976; Martin and Bauer, 1980; Pease, 1980; and Ray and Dupré, 1980), we would anticipate that a frequent mode of ice movement would be a generally southerly flow within the northern Bering Basin. This mode was observed and will be called mode no. 1. The best examples are the maps for February 7-12 1976, March 6-9 1973 (partial coverage), March 13-17 1976, and April 24-30 1975 (with a temporary one-day reversal). On these occasions ice motion was southerly not only over the entire northern Bering but through Bering Strait as well. This mode usually resulted in a dead zone with little or no ice motion on the north side of St. Lawrence Island.

Another mode observed (mode no. 2) also features southerly flow south of St. Lawrence Island, but easterly flow north of St. Lawrence Island, turning in a massive curve around the eastern end of the island. The best example of this was obtained on April 25-31 1973. A second example can be seen during the first half of the April 6-12 1975 data set before a marked transition to another mode takes place. A third example covering most of the study area occurred during April 18-24 1976. Southerly flow through Bering Strait was not observed during these occasions.

The third mode observed features northerly flow within a major portion of the region including Bering Strait. One example of this showing only the eastern Bering Sea and Bering Strait was obtained on February 17-23 1979. A second example showing the central Bering Sea and Bering Strait is the second half of the February 24-March 2 1976 observation following a transition from southerly flow (mode 1). The third example shows this mode operating in the central and eastern Bering Sea between April 9 and 11 1975 following a southerly flow. A fourth example is seen on the April 13-18 1977 data. The fifth example showing only the central Bering Sea and Bering Strait was obtained on May 29-31 1974.

A fourth mode, closely related to the third mode, features northerly flow in the northern Bering, but little or no northerly flow through Bering Strait. In this case, there is a marked spatial deceleration of floes in the region just south of Bering Strait. Two examples were found, each covering only a portion of the study area. The most complete was obtained on February 25-March 4 1974, and the second was obtained March 26-31 1977. In addition to the spatial deceleration with distance to the north, these two examples show ice in-filling the region on the north side of St. Lawrence Island by turning either eastward or westward around the corners of the island.

Landsat coverage is cloud-limited and, therefore, it is possible that other patterns of ice movement exist in the northern Bering Sea. However, it should be pointed out that both northerly flow and southerly flow were observed throughout the region although one might expect one pattern or the other to be eliminated from observation if it were strongly linked to cloudiness. Clearly this is not the case. However, this does not rule out the possibility that some other mode of ice movement has been eliminated from observation by cloudiness. For instance, no observation was obtained showing westward motion throughout the study area. In order to rule this out, buoy trajectories might be used.

2. Unimpeded movement of Ice through Bering Strait.

It appears that when ice participates in an unimpeded flow (i.e. movement not obstructed by stationary ice) through Bering Strait, the ice pack is accelerated as it approaches" the Strait and decelerated upon leaving it. This process takes place roughly over a 2 1/2° latitudinal " zone: acceleration of 50% the original speed per half degree of latitude takes place over the degree of latitude before reaching the strait. Floe speeds appear to be relatively constant *over* the half degree of latitude containing the strait. Deceleration takes place to near the original speed over the next degree of latitude (approximately 110 km).

The shape of Bering Strait is roughly that of two trapezoids arranged with their smaller sides facing each other with a small rectangular region between these smaller sides. The rectangular region has a height of approximately 1/2° and the height of the trapezoids is approximately 1°. The corresponding widths of the region are such that the ratio of the cap to'base of the trapezoids is approximately 0.5.

Taking the density of floes as $\sigma(x,y)$ and their velocity field as $\vec{v}$ we would expect the complete ice budget in any region of consideration to be given by

$$\frac{d\sigma}{dt} = \vec{\nabla}\cdot\sigma\vec{v} + \frac{\partial\sigma}{\partial t}$$

However, with a very short observation period little ice is grown.

Hence $\frac{\partial\sigma}{at} = 0$ and

$$\frac{d\sigma}{dt} = \vec{\nabla}\cdot\sigma\vec{V} = \sigma(\vec{\nabla}\cdot\vec{V}) + \vec{\nabla}\sigma\cdot\vec{V}$$

If the spatial density of ice within the region of observation is constant then $\vec{\nabla}\sigma = 0$

('This is generally observed to be the case. Floes do not appear to pack together in the Bering Strait area when passing through.) We are then left with

$$\frac{d\sigma}{dt} = \vec{\nabla}\cdot\sigma\vec{V}$$

If the ice is not to increase or decrease in concentration within the study area over a period of time, then

$$\frac{d\sigma}{dt} = 0 = \vec{\nabla}\cdot\sigma\vec{V}$$

Since the sides of our trapezoidal observation regions represent barriers to ice motion, only the base and cap can contribute to this divergence calculation, The above condition can be met if the ratio of velocities at the cap and base of the trapezoids is equal to the inverse of the ratio of the lengths of the cap and base. This was generally found to be the case. (See March 6-8 1973, May 29-31 1974, and February 24-March 2 1976.)

A complete investigation of the implications of this result are beyond the scope of this report since a highly detailed analysis including meteorological and oceanographic processes would be required. However, this acceleration behavior explains why a marked condensation of floes is not apparent in the Bering Strait region on satellite images as ice passes through.

3. Reversal times.

Several cases were recorded showing floe movement completely reversed from one day to the next over a large area. This clearly indicates that the time required for a reversal in direction is considerably less than one day. These cases should be examined further in terms of driving mechanisms including oceanic currents and winds.

4. Source of thickened ice in southern Bering Sea.

Southerly flow of ice in the Bering Sea has been observed so often that the process has been referred to as a "conveyor belt." Occasionally highly rafted floes have been observed at the southern end of the belt, giving rise to speculation as to their origin (Martin, private communication). It appears possible that during mode 1 described above, floe compaction takes place in the dead zone on the north side of St. Lawrence Island. During mode 2 these compacted floes are flushed out to join the general southerly flow of the Bering Sea. This process could be responsible for the highly rafted floes which have been observed.

Maps of Measured Ice Displacements

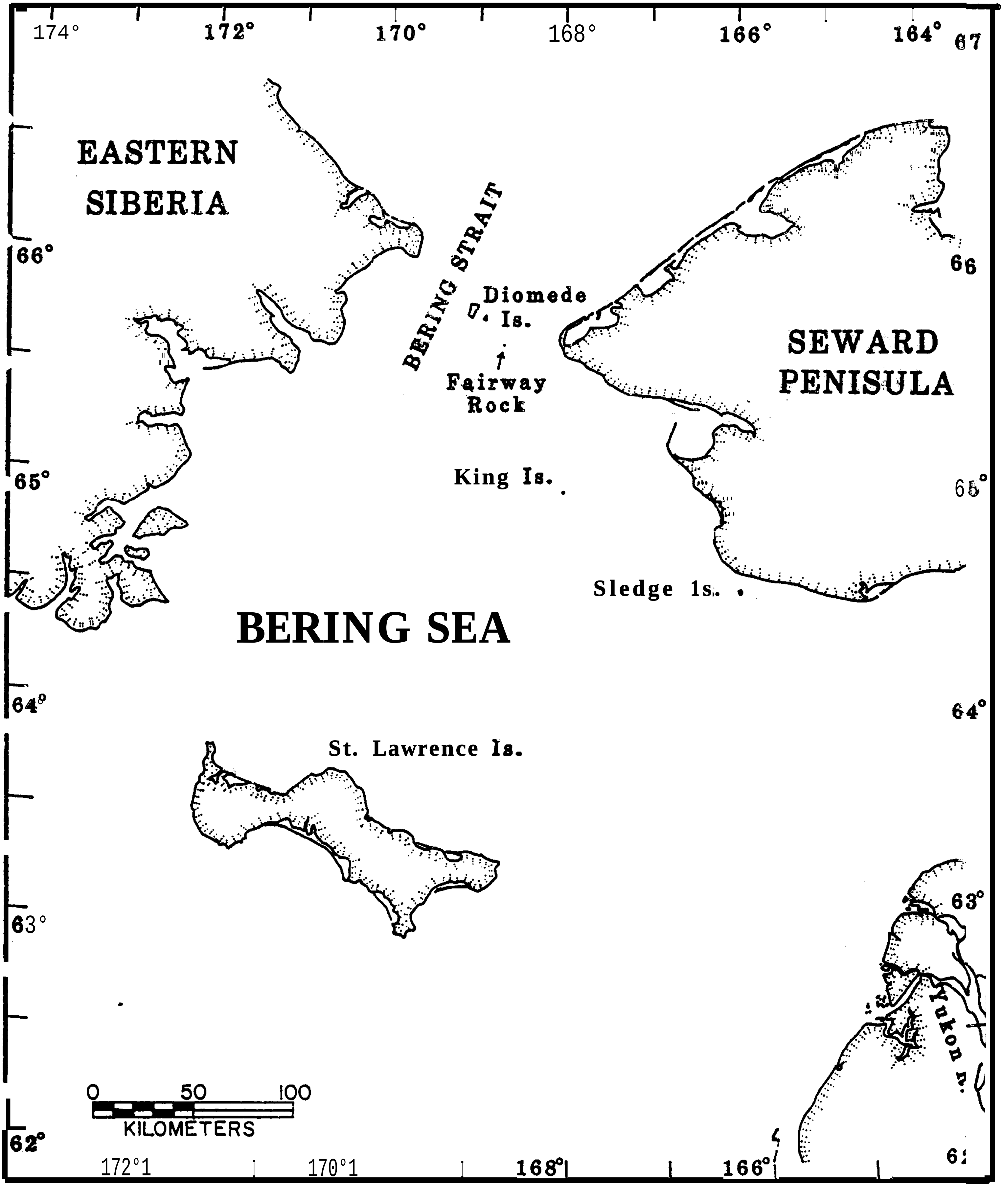
Figures 2 through 19 display the results of the displacement vector field measurements. These maps do not contain geographic place names. For reference purposes, Figure 1 has been prepared showing the study area and labeling the geographic locations pertinent to the discussions of Figures 2 through 19.

Some discussion of the format of these figures is required in order to develop an understanding of the results contained. The day-to-day sequence of areal image extent moves from east to west at a rate of approximately 1/3 the full image width. As a result, floe movement will remeasured for each two-day image pair over an area approximately 2/3 the full image width. However, because a given location on the earth's surface is imaged three days in succession, it will also be possible to measure the same floe's motion between the second and third day as well. These two areas will overlap an amount equal to 1/3 a full image width. Hence, under ideal conditions, the study area could be divided into a number of north-south strips, each 1/3 a full Landsat image width which show two consecutive displacements for the floes contained. For instance, the first strip would contain displacements between the first and second days only. The second strip would contain displacements between the first and second days, and the second and third days. The third strip would contain displacements between the second and third days and the third and fourth days. This is largely how these figures are organized except that the first two strips are combined as it is obvious which vectors are one day displacements and would have been in the first strip. At the bottom of each strip the dates are given between which the first displacements shown within that strip were measured.

Vector displacements are usually designated as tailless arrows. In the case of a two-day displacement measurement the combined displacement will be designated as a two arrow pair (head to base). Occasionally a displacement measurement was possible on only the second day of a two-day pair. In that case the vector arrow is drawn with tail feathers. All vector arrows from the first two-day pair have no tail feathers.

In all cases the displacement in km is given adjacent to the vector. In a few extreme cases only two-day displacement measurements were possible (clouds or lack of imagery eliminating the middle day). In this case “two-day” is printed adjacent to the displacement measurement.

FIGURE 1



174°
172°
170°
168°
166°
164°
67
EASTERN
SIBERIA
BERING STRAIT
Diomede
Is.
Fairway
Rock
SEWARD
PENISULA
66°
66
King Is.
65°
65°
Sledge 1s.
BERING SEA
64°
64°
St. Lawrence Is.
63°
63°
Yukon R.
0
50
100
KILOMETERS
62°
172°
170°
168°
166°

Figure 2

March 6-8 1973

The area mapped during this period was limited to the Bering Strait-eastern Bering Sea region. This appears to have been fortuitous because an understanding of the ice motions observed required just such a data set.

During this time ice is being driven southward through Bering Strait and down the western Bering Sea past St. Lawrence Island. It may be worthwhile to observe that the ice appears to be accelerated where it passes through constrictions: at Bering Strait it accelerates from daily displacements around 16 km/day to displacements around 32 km/day and then decelerates to displacements around 25 km/day halfway between Bering Strait and St. Lawrence Island. The ice then accelerates to displacements on the order of 35 km/day as it enters the channel between St. Lawrence Island and western Siberia. The one floe actually observed to pass between St. Lawrence Island and Siberia possessed a displacement " of nearly 70 km/day.

Two dead zones were observed associated with this motion: the first is located north of the Seward Peninsula and to the east of the stream of ice through Bering Strait. The second is located to the east of the stream and north of St. Lawrence Island. These dead zones can easily be explained in terms of land masses acting as obstructions to ice motion.

FIG 2

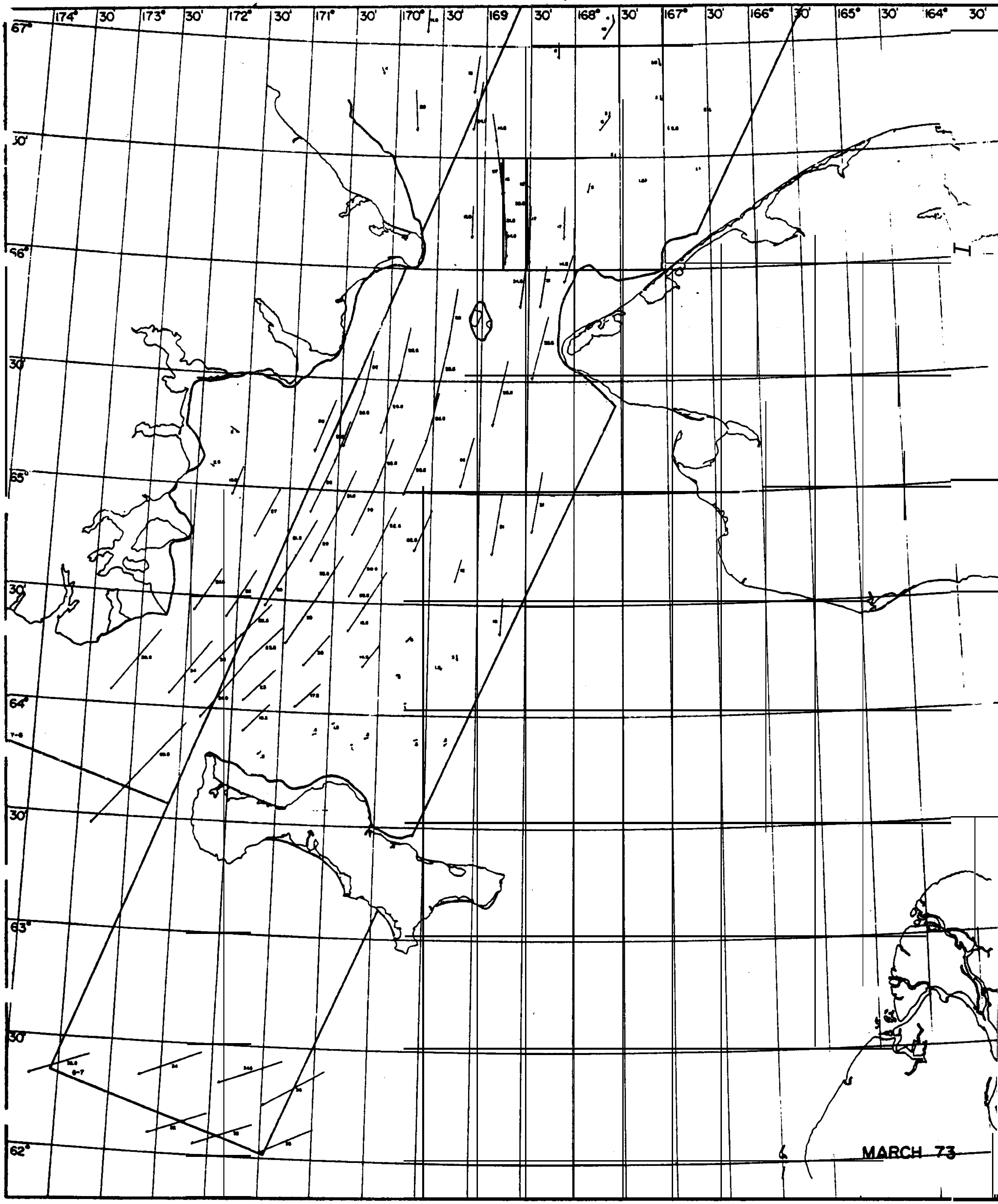

174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
MARCH 73

Figure 3

April 25-31 1973

It would appear that the same pattern characterized ice movement in the northern Bering Sea for at least the first five days of this six-day period. This pattern can be described as eastward-traveling ice in the region north of St. Lawrence Island turning southward as it enters the eastern Bering Sea. Associated with this is a counterclockwise gyre in the entrance sector of Norton Sound. Ice motion in the Bering Strait region is slight and not coherent during this time. The largest displacements were observed off the southwest corner of the Seward Peninsula.

Fig. 3

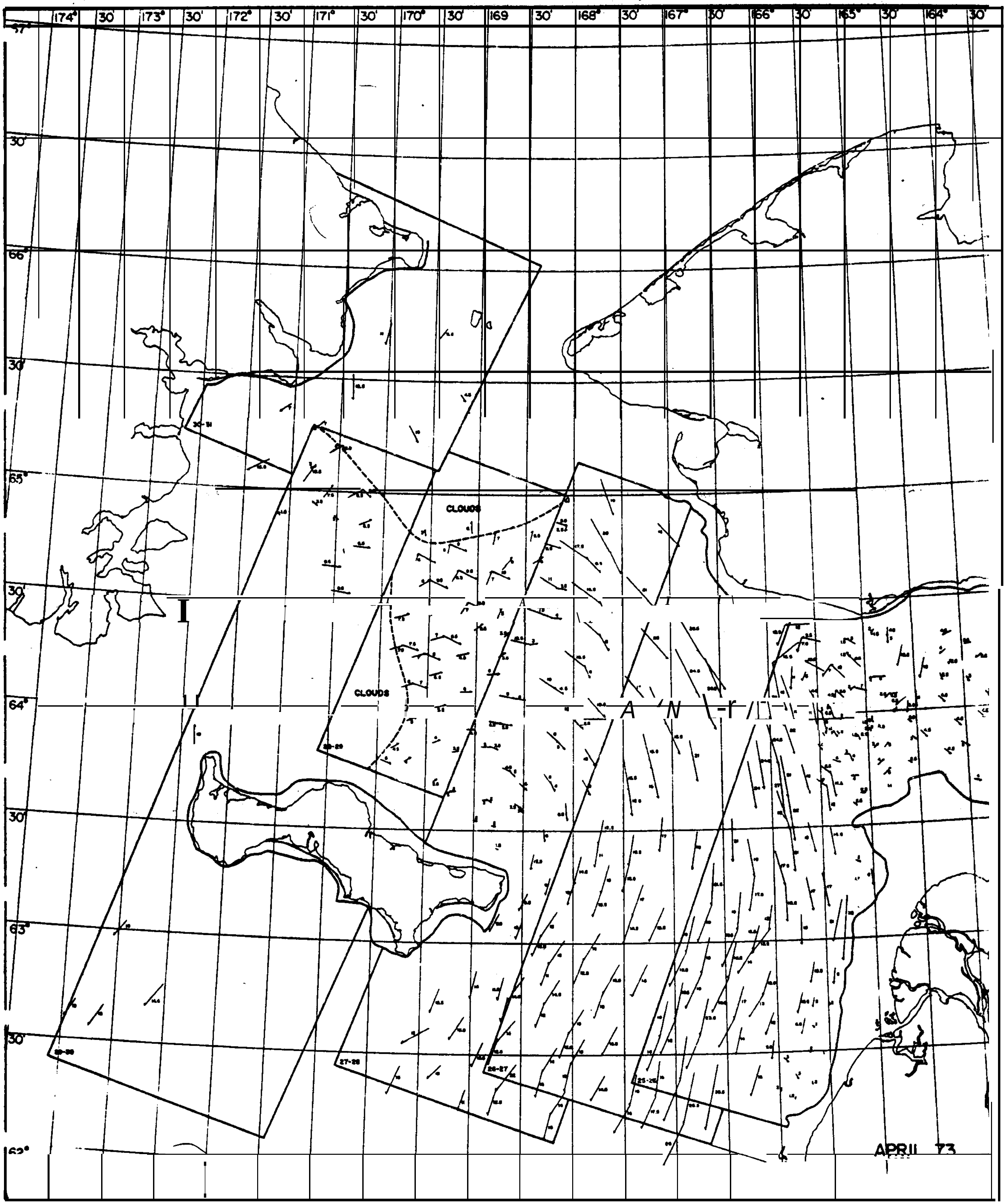

174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
CLOUDS
CLOUDS
30-31
29-29
27-28
26-27
25-26
APRIL 73

Figure 4

February 9-11 1974

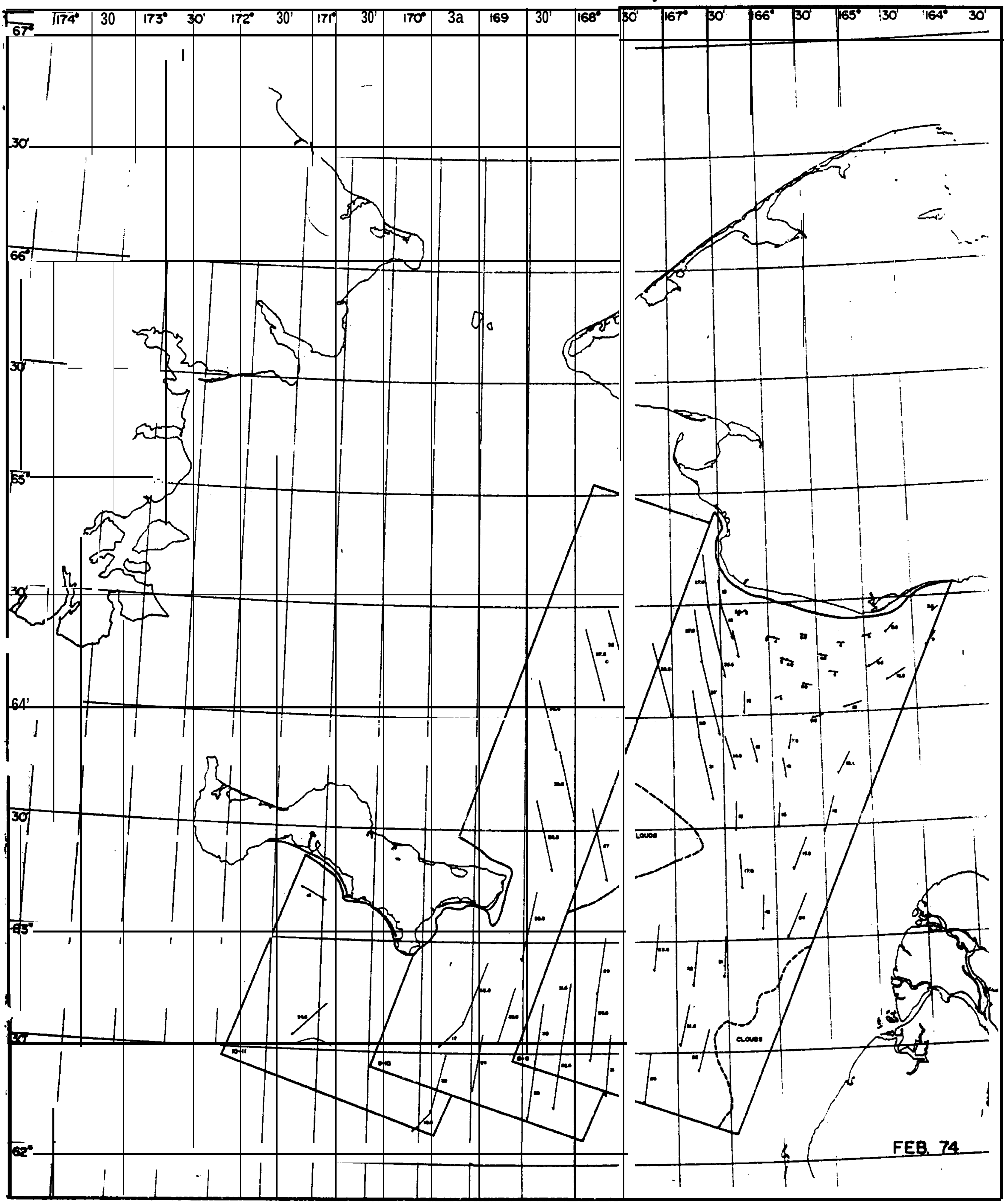
Only a portion of the study area was mapped during this period. The following zones of uniform ice motion can be identified:

1 . A zone of large southward-trending displacements in the eastern Beaufort Sea, streaming around the eastern end of St. Lawrence Island with displacements on the order of 35 km/day.

2. A zone of medium (12-20 km/day) southward-trending displacements in the extreme eastern side of the Beaufort Sea.

3. A zone of small (5 km/day) displacements curving around the northwestern end of Norton Sound.

Fig. 4



174°
30
173°
30'
172°
30'
171°
30'
170°
3a
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
CLOUDS
CLOUDS
FEB. 74

Figure 5

February 25-March 4 1974

The data recorded here were obtained over a period of seven days containing five, one-day observation periods, four of which were adjacent. These data indicate a period of northerly ice flow within the northern Bering Sea. However, ice motion through Bering Strait does not take place: ice displacements become smaller with distance from south to north. This indicates a general compaction of ice into the northern Bering Sea area.

Fig 5

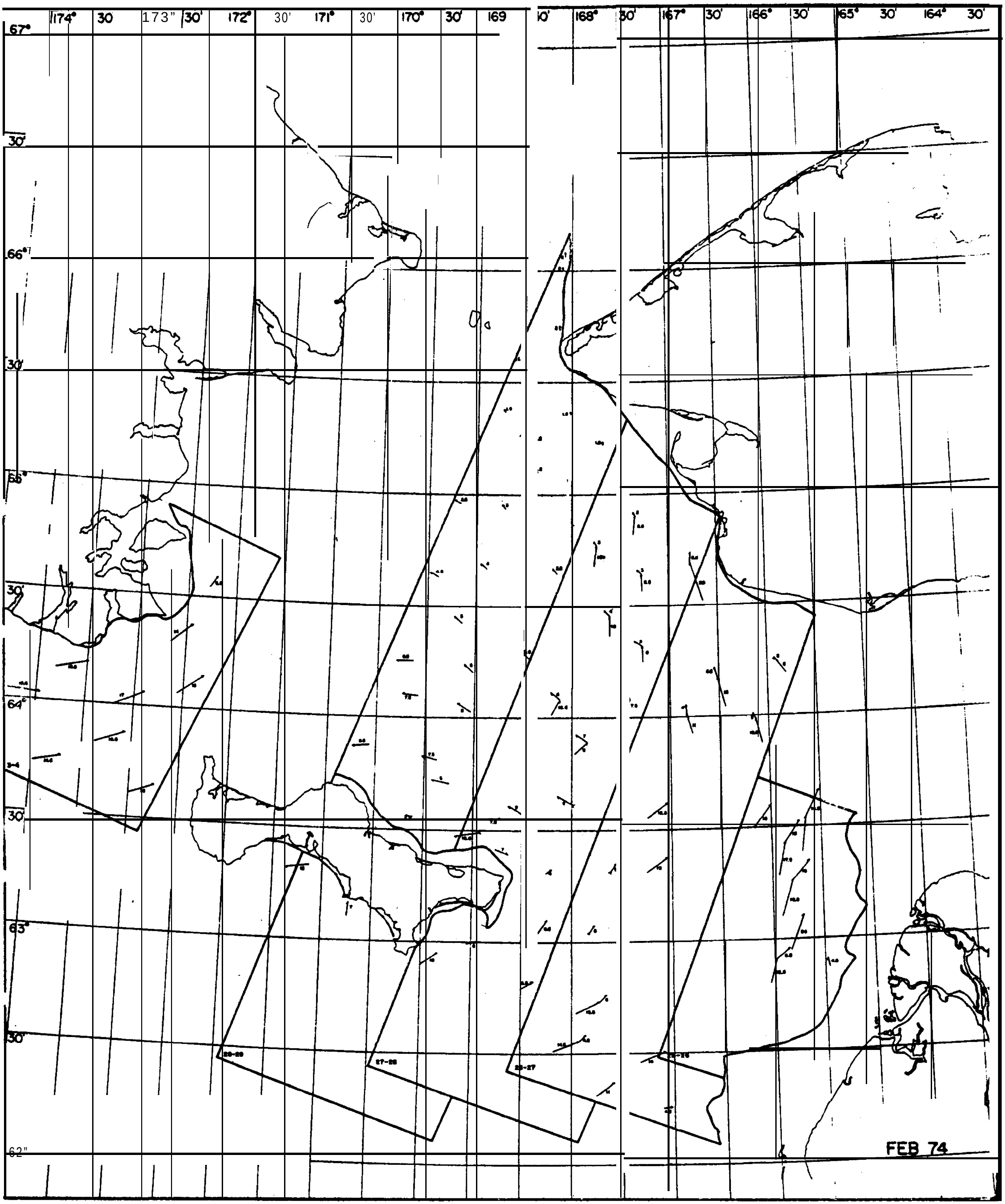

174°
30
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
26-29
27-28
25-27
FEB 74

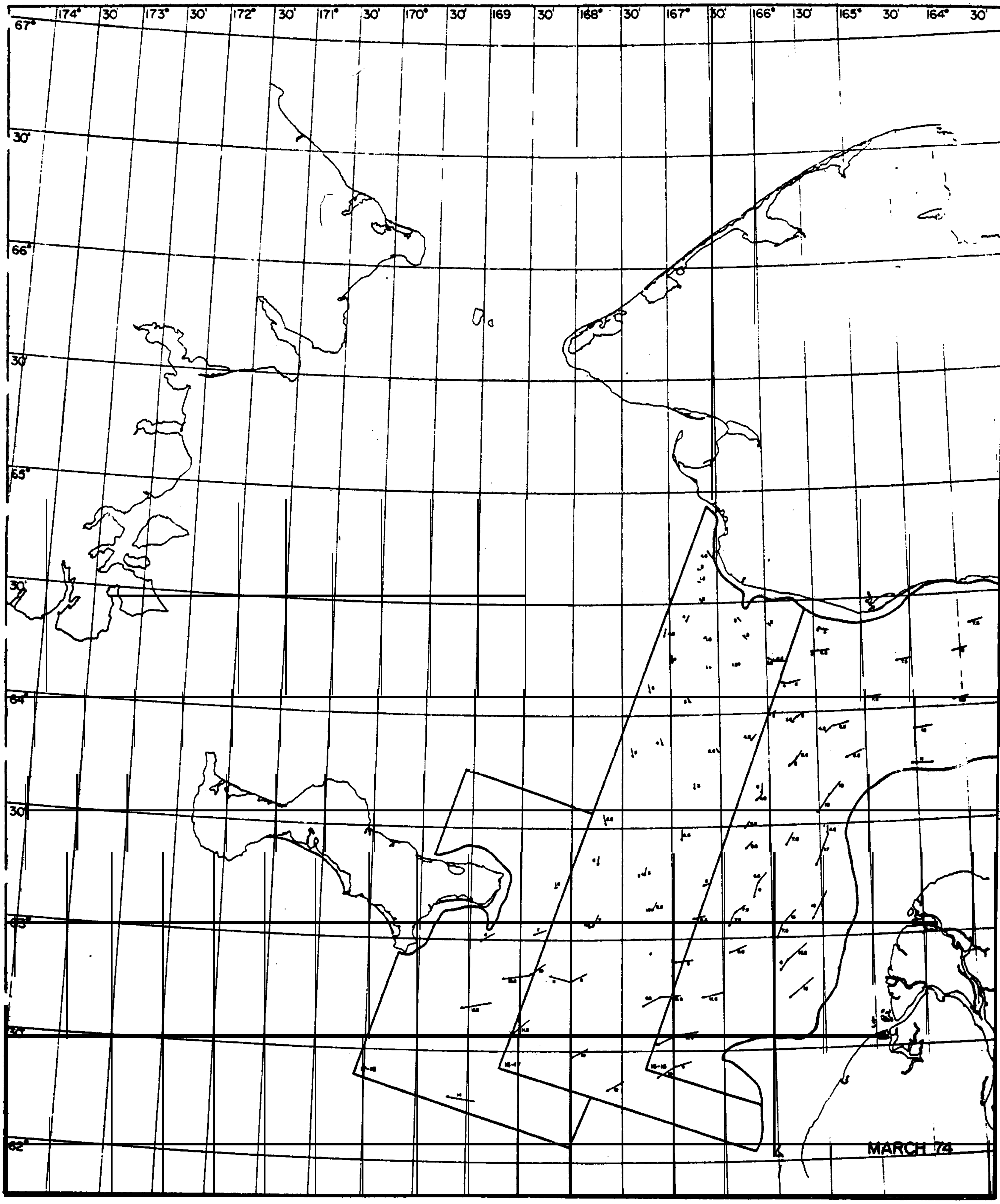
Figure 6

March 15-18 1974

Only a portion of the eastern Bering Sea was mapped during this three-day period. The chief value of this map is that it shows an occasion when the daily displacement of ice exiting Norton Sound was greater than the displacements measured in the adjacent Bering Sea. The pattern found showing ice exiting Norton Sound to the south and then turning westward below St. Lawrence Island is rather interesting and also appears to be unusual. Note that the pattern extends across the boundaries of the daily areas mapped and, therefore, is not simply a temporal phenomenon.

During this period there is a dead zone just south of Sledge Island beyond the mouth of Norton Sound.

Fig 6



174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
MARCH 74

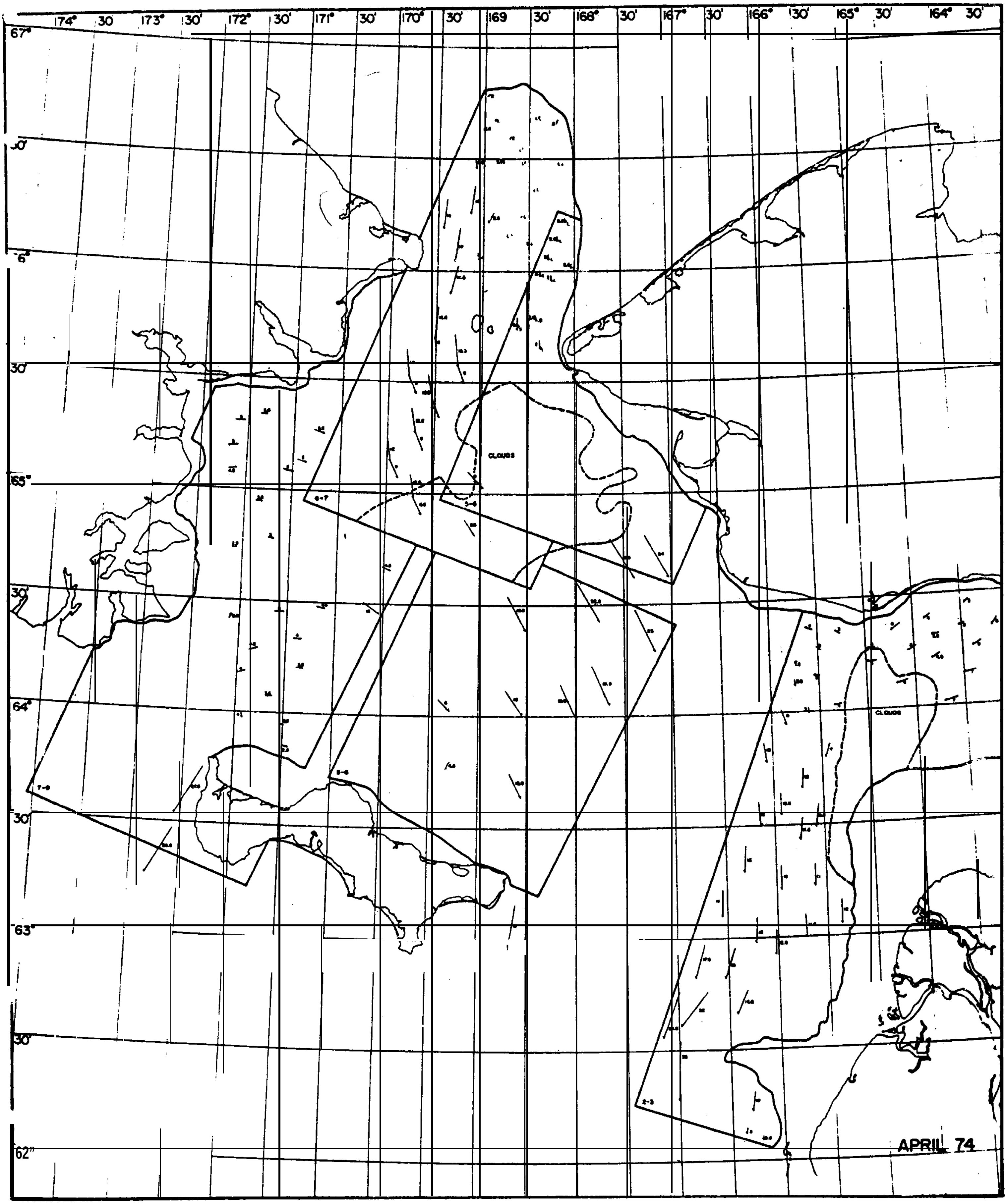
Figure 7 "

April 2-8 1974

It would appear that ice movement patterns remained relatively constant throughout this period. Ice is seen entering the northern Bering Sea through Bering Strait and turning to pass to the east of St. Lawrence Island. Ice in the western Bering Sea is being driven eastward' at relatively small velocities. Ice to the northwest of St. Lawrence Island is curving around the northwest corner of the island to join this stream while ice immediately to the south is being driven southward at displacements on the order of27 km/day,

Ice in the vicinity of Bering Strait appears to accelerate by a factor of at least 2 while passing through the strait. However, here it is originating from a solid ice edge just north of the strait. In this case a spatial deceleration of floes is not apparent south of the strait.

Fig 7



174°
30
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62"
CLOUDS
CLOUDS
APRIL 74

Figure 8

May 29-31 1974

Only the central Bering Sea was imaged during this period. Ice motion during this time was northerly through Bering Strait with daily displacements through the strait as large as 46 km. As seen during other periods of major floe transit in Bering Strait, floe velocities are greater through the strait than on either side. This indicates an acceleration of floes through the strait. The magnitude of the acceleration here appears to be approximately 50% per half degree of latitude, starting 1° south of Bering Strait. Almost all the ice passing through Bering Strait was passing east of the Diomede Islands, the western channel being essentially ice free. It is perhaps worthwhile to observe that the column of ice passing through the eastern channel exhibits a generally uniform floe density throughout its length despite the spatial acceleration and deceleration described.

Upon entering the Chukchi Sea, the ice appears to be making a small detour to the east before continuing its northerly motion.

There is a zone of small and incoherent motions just north of St. Lawrence Island. These vectors are representative of the motions within a plume of remnant ice extending north from St. Lawrence Island.

Fig 8

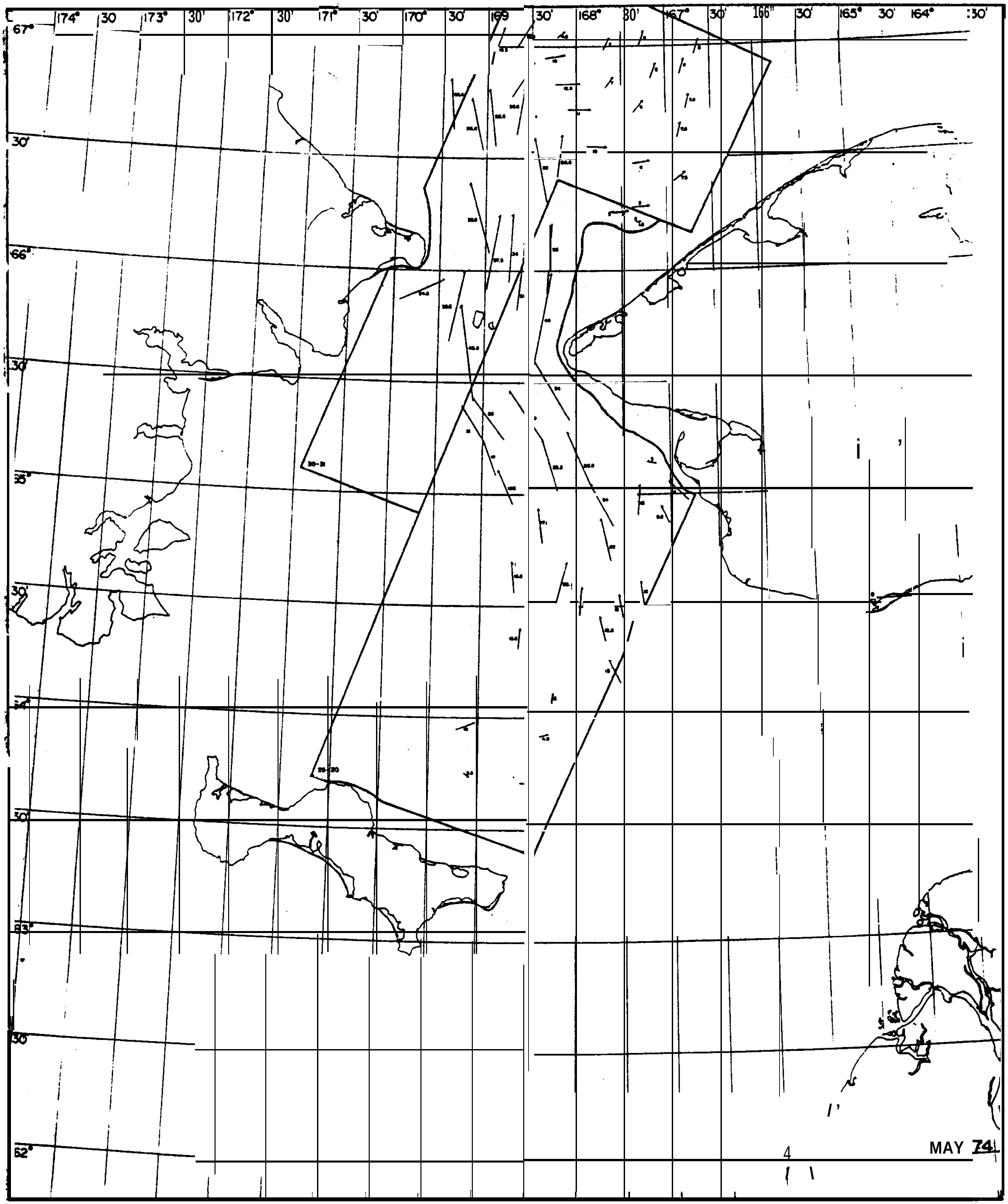

67°
174°
30
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
30-31
29-30
MAY 74

Figure 9

February 23-26 1975

The data represented here were obtained over a span of four one-day periods during which several two-day displacements were measured. It appears that both spatial and temporal changes are recorded here: within the block designating the total coverage for February 22-23 the longer displacements (vector arrows without tails) range from44 to 33 km/day. The displacements in the same area the next day are on the order of 8 km. In one case, the floe which had been transported 44km during February 22-23 only traveled 6.5 km between the 23rd and 24th. This clearly indicates a rapid deceleration of floes between these dates.

On the other hand, the dead zone within the area mapped for the 23rd-24th may well be at least partially a true spatial variation: even within this block a decrease in displacement from east-to-west is clearly obvious.

Nearby displacements the next day (February 24-25) are considerably larger and measurements extend into Bering Strait where southward displacements on the order of 15 km/day were measured. However, these displacements decrease to the south and become as small as 5 km/day.

Just to the west, on the next day a displacement as great as 61 km was measured as part of a stream of southward-moving ice between St. Lawrence Island and eastern Siberia.

FIG 9

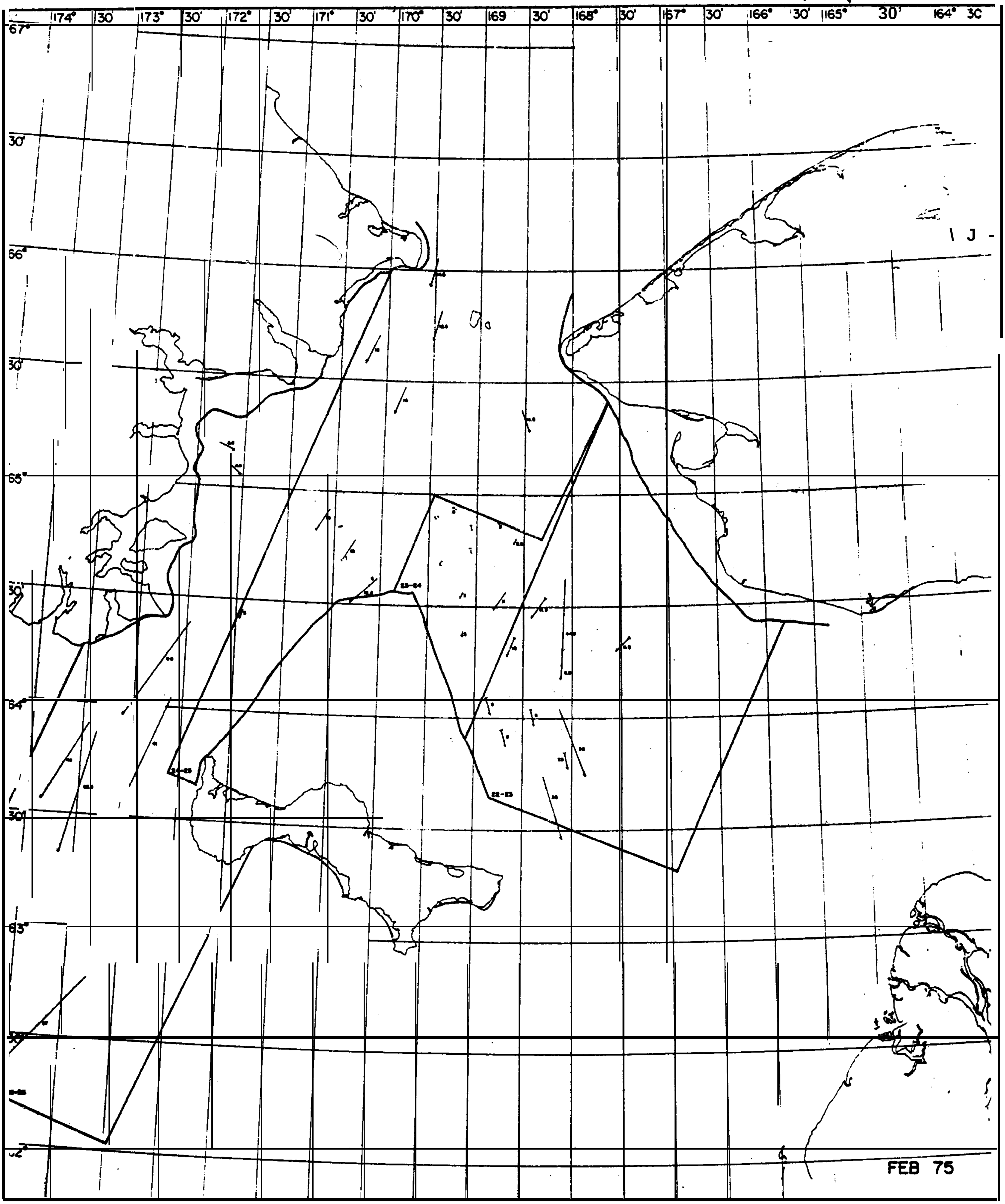

174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
FEB 75

Figure 10

April 6-12 1975

During this six-day period, a major reversal in floe motion is recorded. At the beginning, ice can be seen streaming down the eastern side of the Bering Sea at speeds up to 47 km/day. A counterclockwise gyre generated by this motion can be seen at the entrance to Norton Sound.

On the fifth day, the ice in the region north of St. Lawrence Island can be seen making an abrupt turn from eastward motion (which would have it continue on around to join the southward-moving stream in the eastern Bering Sea) to northerly motion. Also on the fifth day, ice can be seen passing through Bering Strait with, for the most part, decreasing speed with distance north. The Chukchi Sea above Bering Strait is covered with a uniform, compact sheet of ice. Thus, ice motion through Bering Strait is restricted at this time.

There is some evidence of a second change in direction of ice motion south of Bering Strait on the sixth day from northerly to westerly ice motion, while within the Bering Strait, ice continues to move in a northerly direction.

Fig.10

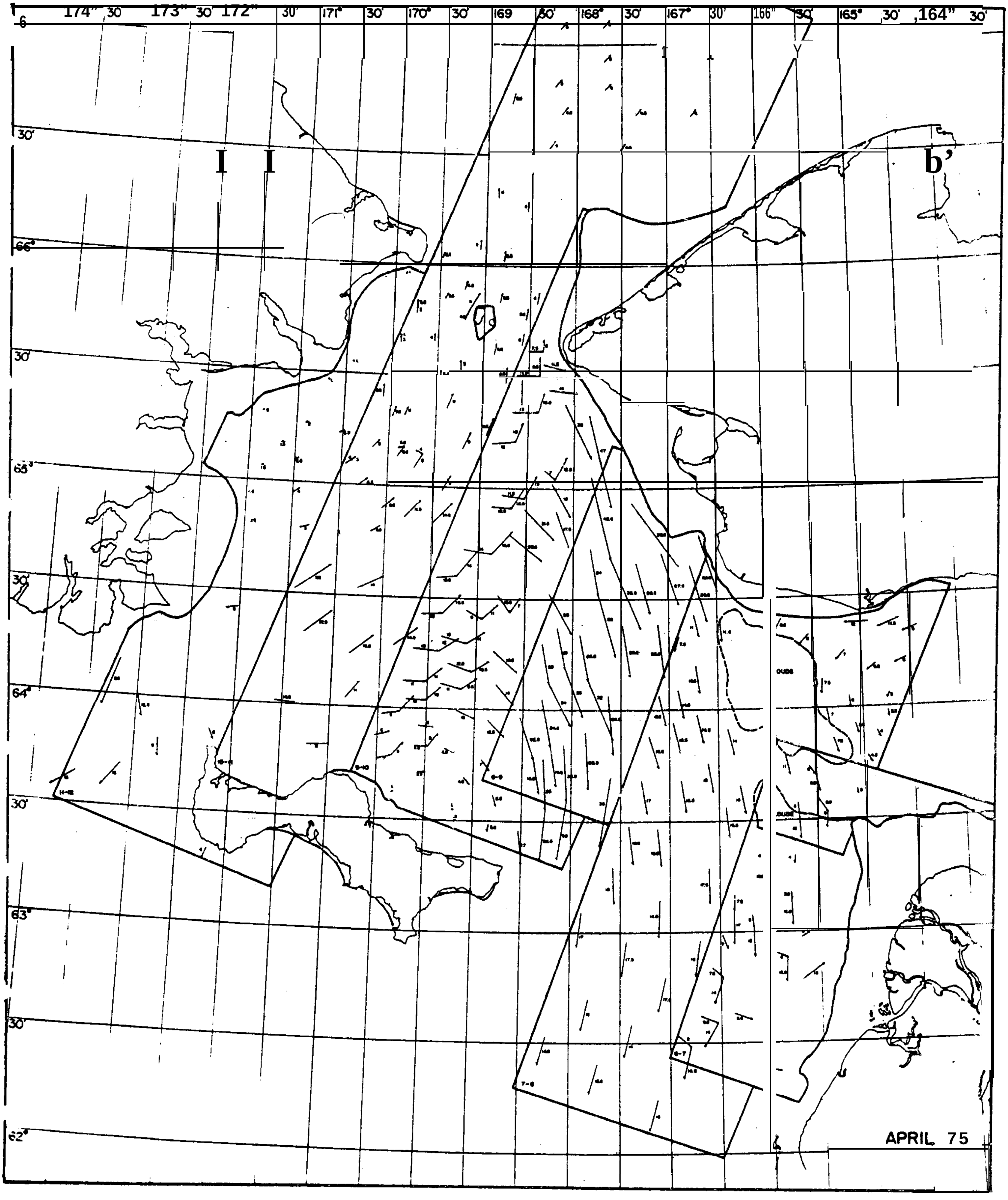

174° 30' 173° 30' 172° 30' 171° 30' 170° 30' 169 30' 168° 30' 167° 30' 166° 30' 165° 30' 164° 30'
66°
65°
64°
63°
62°
30'
I I
b'
APRIL 75

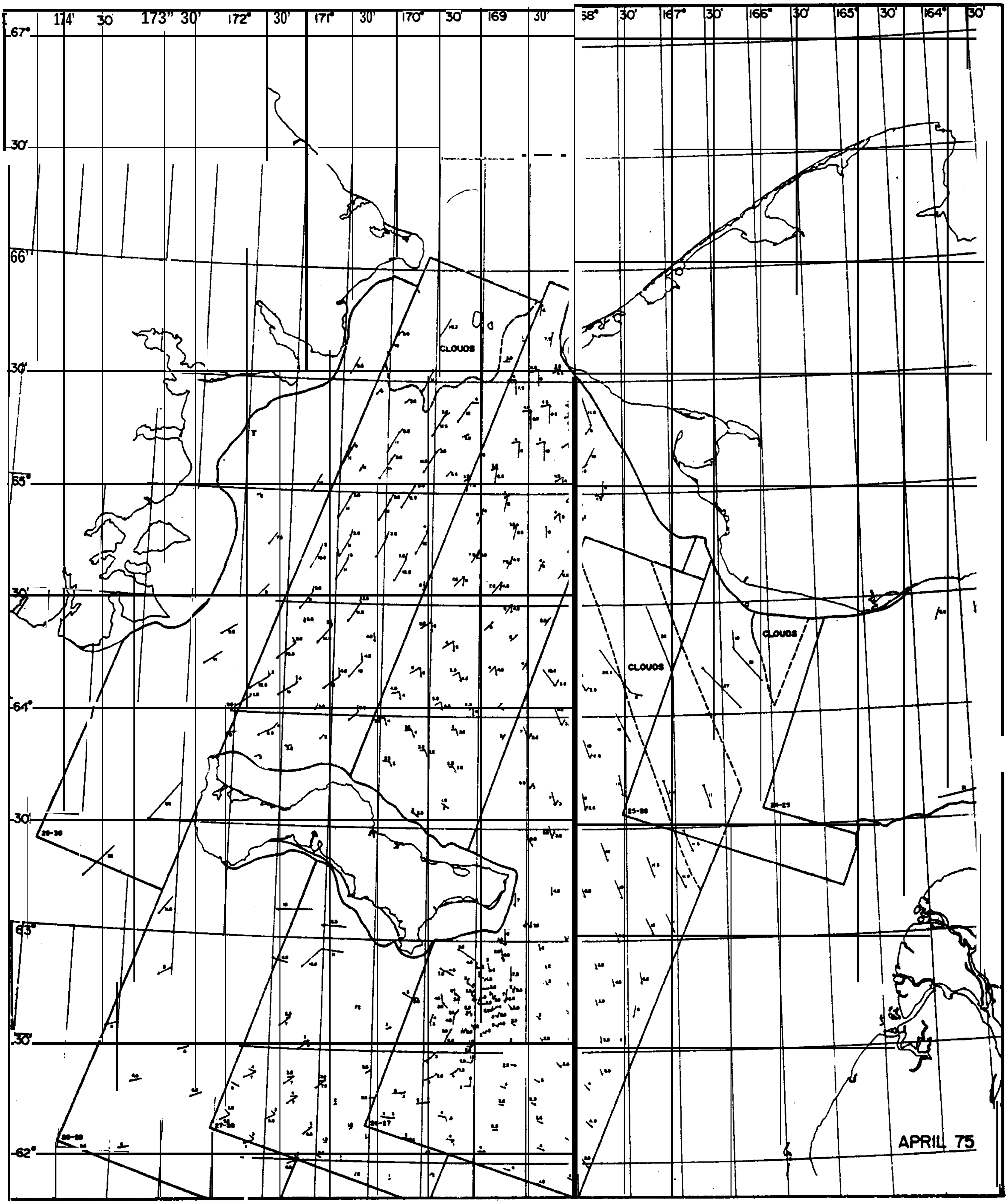
Figure 11

April 24-30 1975

During this six-day period ice motions in the northern Bering Sea were largely southward, except for one day when northerly displacements took place. As part of this reversal we see small northerly displacements through the eastern Bering Strait on April 27-28 followed by a southerly displacement of 10 km the next day. During this period there is no true dead zone north of St. Lawrence Island although displacements there are only a few km/day.

Off the southeast corner of St. Lawrence Island there is what could be described as a “zone of confusion” characterized by random ice motions.

Fig 11



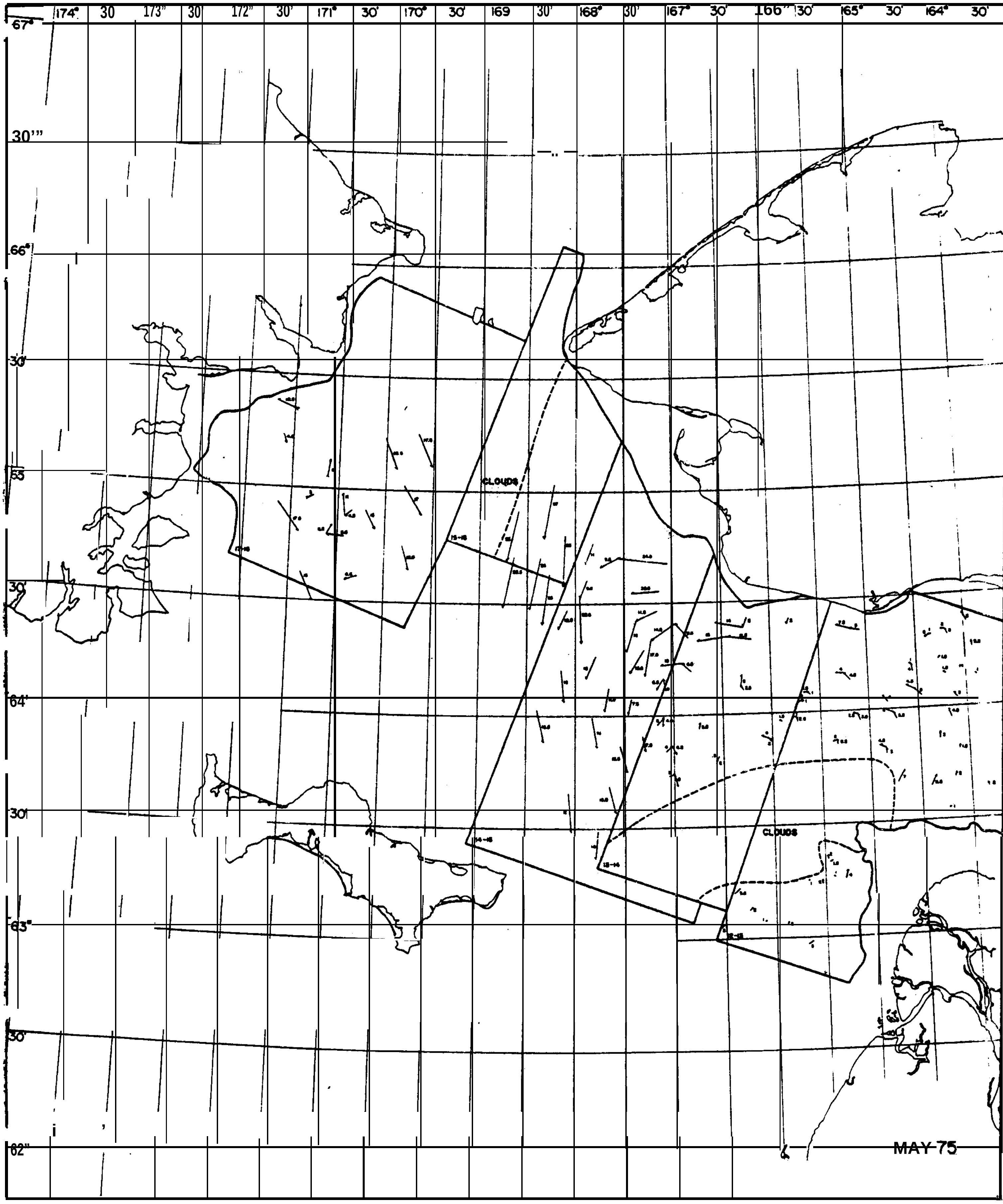
174'
30'
173°30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
CLOUDS
CLOUDS
CLOUDS
APRIL 75

Figure 12

May 12-18 1975

Ice motion during this six-day period is not extremely coherent. In Norton Sound, the eastern Bering and the western Bering Sea areas, ice motions in almost any direction can be found. Only in the central Bering Sea during the middle of the period can a pronounced pattern of motion be found. This pattern is characterized by largely southerly motion with speeds around 25 km/day.

Fig. 12


174°
30
173°
30
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65
30'
64'
30'
63°
30'
62°
CLOUDS
CLOUDS
MAY 75

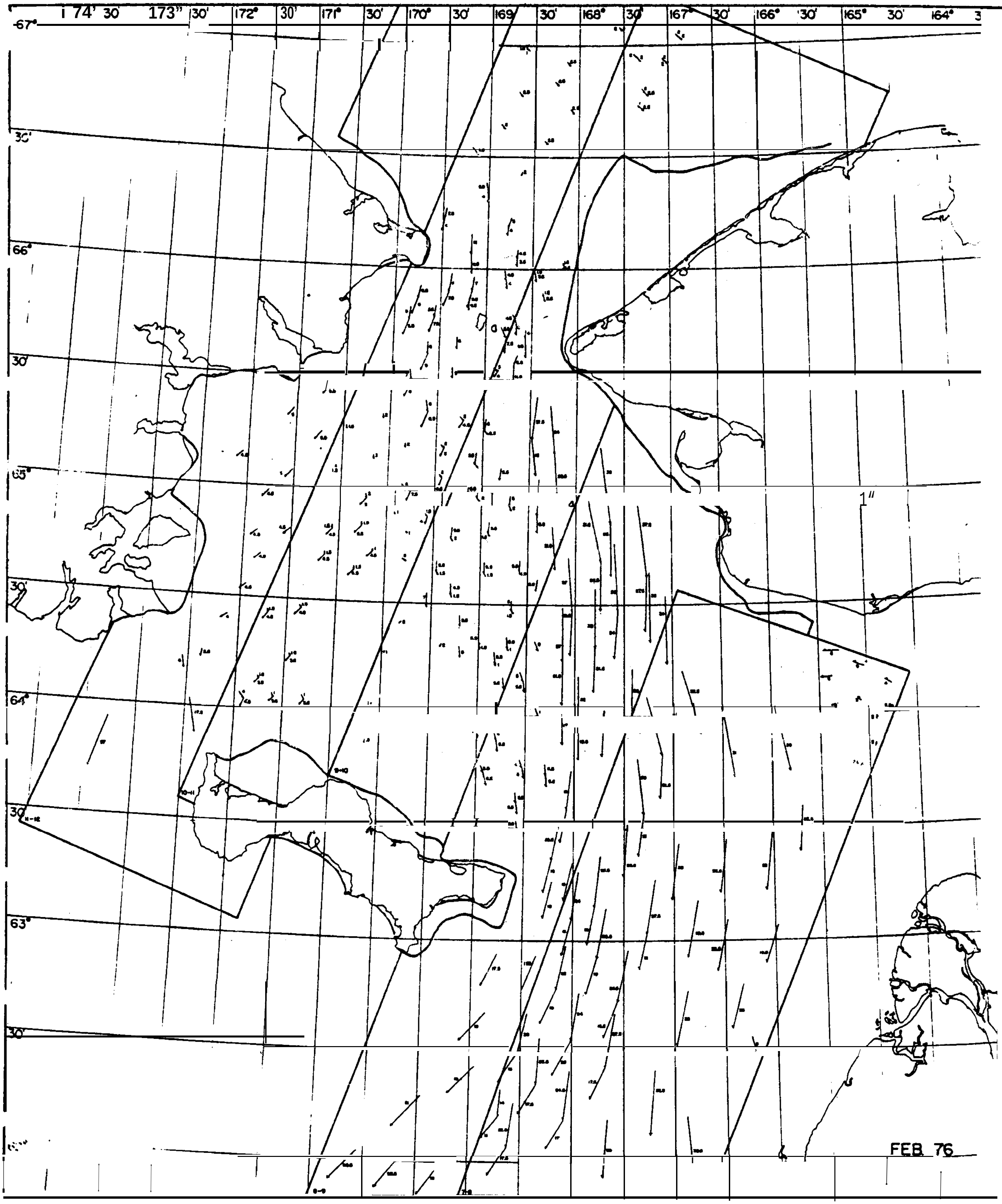
"Figure 13

February 7-12 1976

Data represented here were obtained over a span of five days during which ice floe motion was generally from north to south without any apparent motion reverses. In spite of the east-to-west delay in spatial coverage, the picture generated appears surprisingly coherent: several zones of uniform ice motion can be seen with their boundaries extending across the boundaries of daily satellite coverage. This behavior lends credibility to the concept of considering this map as a "snapshot" of ice motions during this time. For this reason, it may be useful to discuss these zones as if they represent posts of a simultaneous overall pattern of ice motion in the study area at this time. These zones are:

1. The extreme southern Chukchi Sea with ice motions from northwest to southeast, all in the vicinity of 2.5 km/day. Examination of the imagery shows that Chukchi Sea ice is being extruded through Bering Strait at this time. Arching is clearly observable.
2. The Bering Strait and north-central and northwestern Bering Sea zone characterized by ice motions on the order of 5 km/day largely to the south.
3. A dead zone extending north of St. Lawrence Island with very small ice displacements (around 1 km/day).
4. The eastern Beaufort Sea characterized by quite large southerly displacements on the order of 25-30 km/day.
5. A counterclockwise gyre in western Norton Sound (discussed in Stringer and Hufford, 1982). .

Fig 13



174° 30'
173°
30'
172°
30'
171°
30'
170°
30'
169°
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
FEB 76

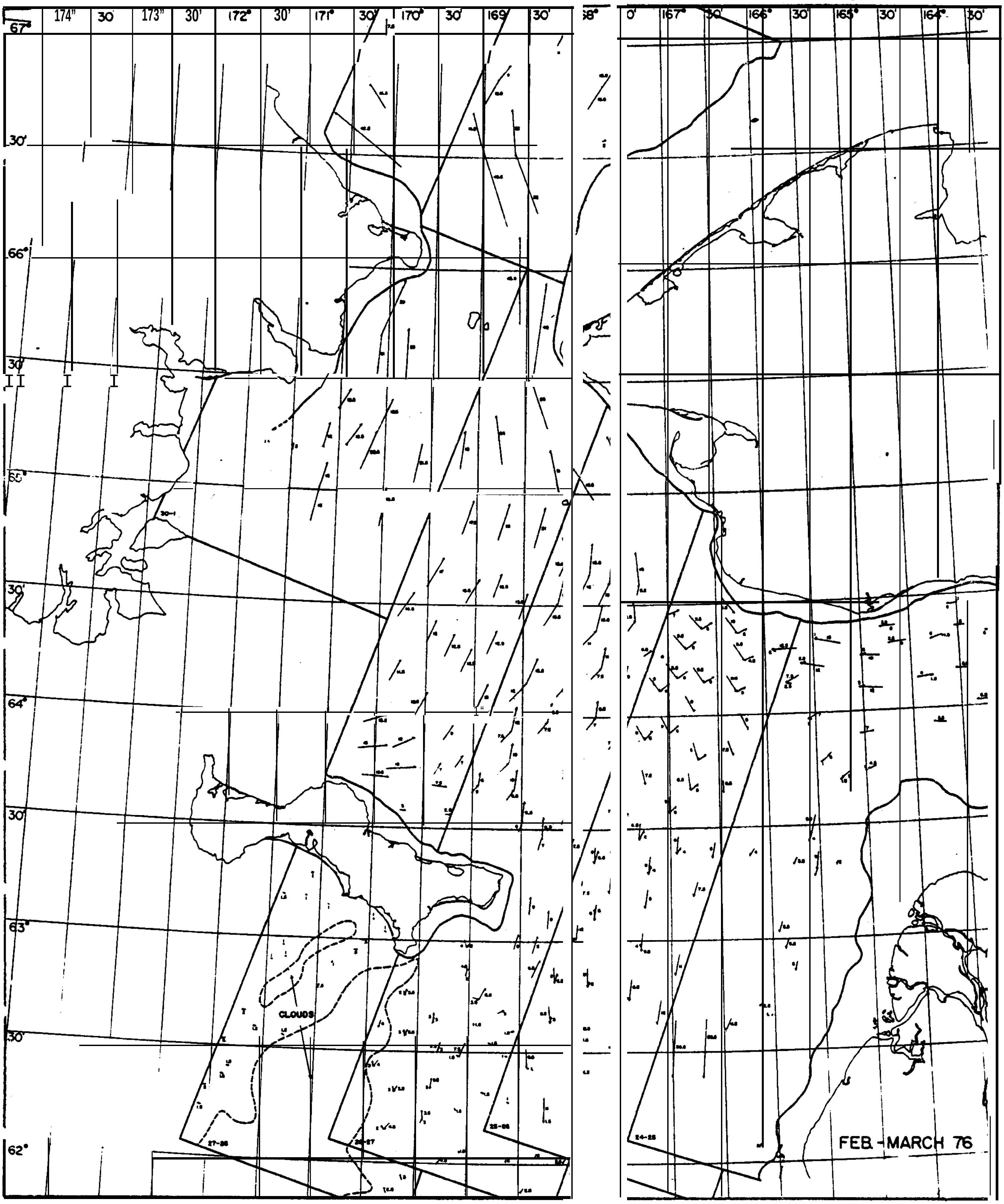
Figure 14

February 24-March 2 1976

Data represented here span a period of eight days between February and March. During this time it appears that a major reversal in the overall motion takes place: from southward to northward motion in the eastern Bering Sea and from westward *to* eastward motion in northern Norton Sound. The reversal is most abrupt in the region between St. Lawrence Island and the Yukon Delta: for example a 15 km southward displacement of a floe one day is followed by a 12 km northward displacement by the same floe the next day. To the north, the reversal is less abrupt and takes place over a period of two days, with floes turning counterclockwise.

Ice motions through Bering Strait were observed at the end of this observation period. It is interesting to note that on those days ice displacements south and north of the strait are smaller than ice displacements through the strait by a factor of two within half a degree of latitude and by a factor of four within a degree of latitude.

Fig 14



174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169°
30'
168°
0'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
CLOUDS
27-28
26-27
25-26
24-25
FEB.-MARCH 76

Figure 15

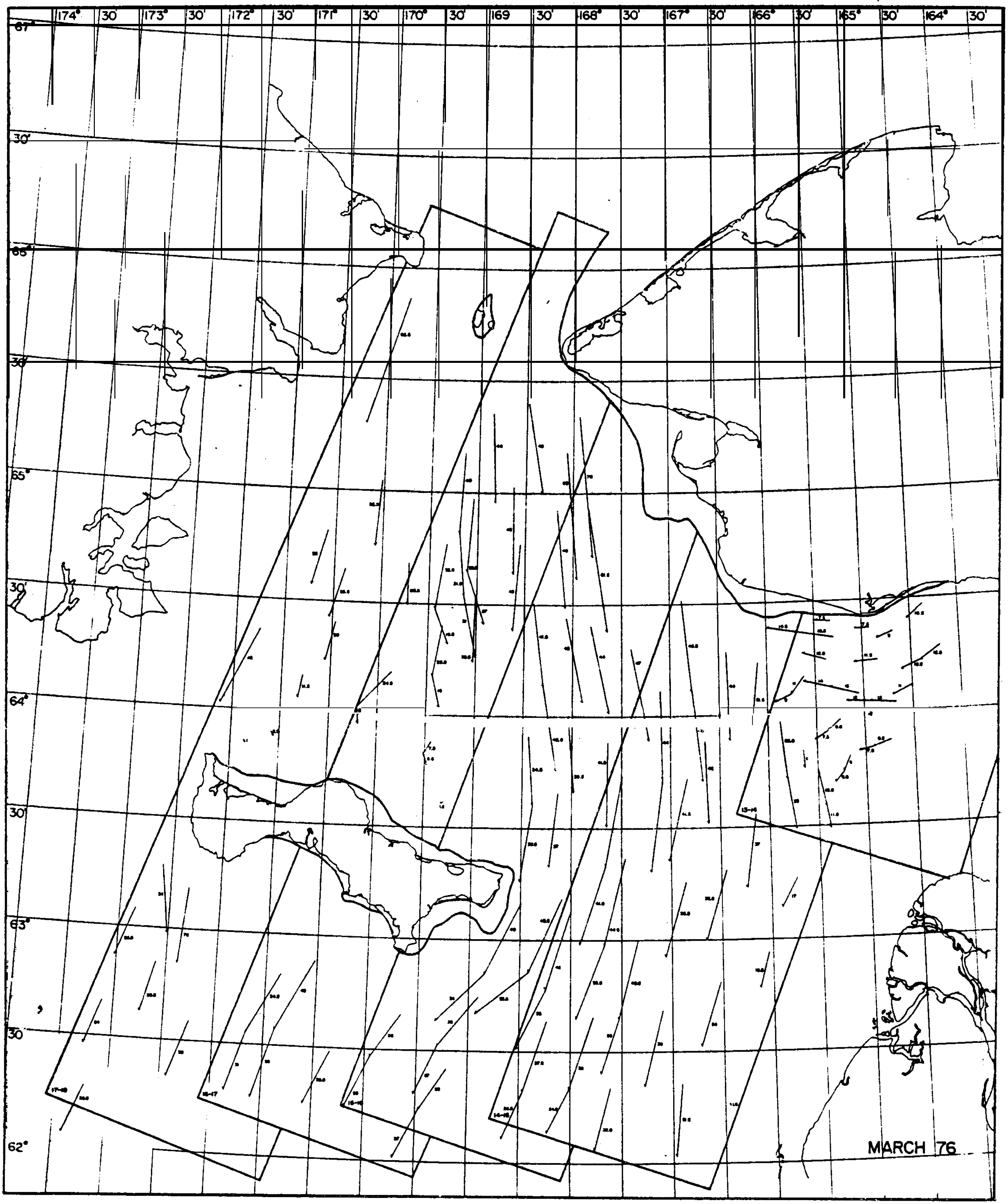
March 13-18 1976

Ice motions were monitored over a period containing five one-day displacement pairs. Displacements in the main stream of ice motion in the eastern Bering Sea range from 45 km/day to 70 km/day in the far north to 25 km/day in the far south. The ice can clearly be seen to be guided around St. Lawrence Island leaving a dead zone with small daily displacements north of the island. During this period, two-day displacements on the order of 80 km/day were commonplace.

Only one displacement was measured in the vicinity of Bering Strait. That daily displacement was 65 km. However, ice was continuously passing through the strait in great quantity. Deformation of floes is taken for the reason that only one floe could specifically be tracked through the sound.

Ice in the mouth of Norton Sound was traveling westward, at right angles to the southward-moving Bering Sea ice. Apparently floes leaving Norton Sound perform an abrupt 90° turn upon leaving the sound, although no floe was actually observed to make this transition. One reason for this is that shearing forces in the transition region may deform transiting floes sufficiently through breakage that they are no longer recognizable and, therefore, not mapped through the turn.

Fig 15



174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
MARCH 76

Figure 16

April 18-24 1976

The ice in the northern Bering Sea generally appears to be following the same pattern throughout this six-day period with some changes during the fourth and fifth days in the northern sector of this region. This general pattern can be described as west-to-east motion in the western Bering Sea, turning south when past the eastern end of St. Lawrence Island and traveling parallel to the Alaskan coastline. During this time, ice motions in the Bering Strait region were very small. Some ice was pushed into the mouth of Norton Sound but displacements just a few km into the sound were quite small. The largest displacements during this time were under 20 km/day while the average was somewhere around 10 km/day,

Fig 16


174°
30'
173°
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30
67°
30'
66°
30'
65°
30'
64°
10'
63°
30'
62°
23-24
20-21
21-22
22-23
APRIL 76

Figure 17

March 26-31 1977

Only spotty coverage was achieved during this five-day period. However, it appears that the same pattern of movement may have taken place throughout the period: ice is seen driven into Bering Strait from the south. Ice south of St. Lawrence Island is being driven eastward at speeds as great as 40 km/day. Earlier, ice was seen to be driven eastward into Norton Sound. This could be part of the same pattern.

North of St. Lawrence Island ice is turning northward and compacting into the Bering Strait region. The Chukchi Sea north of Bering Strait appears to be quite compact. In the few cases that two-day displacements can be seen, the second day displacements are 10% of the first day displacements, indicating that perhaps the entire region even south of Bering Strait had become compacted. Examination of the satellite imagery suggests that this is the case.

Fig 17


174°
30'
173"
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
65°
64°
63°
62°
MARCH 77

Figure 18

April 13-18 1977

Bering Sea ice motion within this six-day period appears to have been largely northward except for one day with small eastward displacements just south of the Seward Peninsula during the third day of observation.

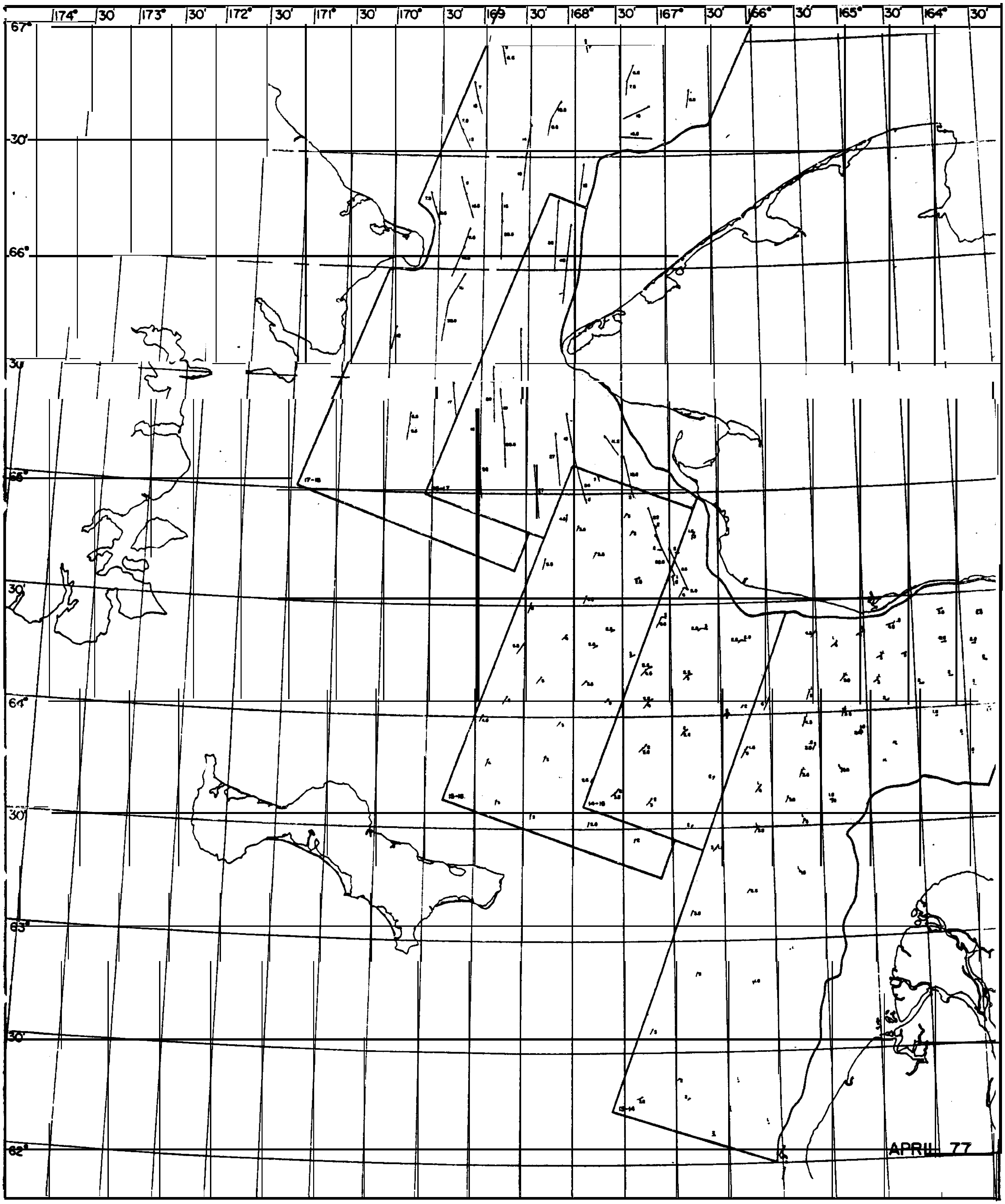
During the early part of this observation period ice is seen to be driven into Norton Sound, turning clockwise into the sound as it enters from the south. This motion leaves a dead zone on the south side of the sound.

Ice motions in the adjacent Bering Sea continue to be northerly while ice stops moving into Norton Sound and exits with very small (∿ 1 km) displacements. On the third day, the ice in the area south of the Seward Peninsula makes a small (1 to 3 km/day) eastward excursion. This is followed by large northerly motions on the fourth day.

It was possible to monitor two floes for three days just west of the southwestern corner of the Seward Peninsula. The motion of these floes demonstrates the motion just described.

During the next two days northerly motions took place through Bering Strait, with speeds on the eastern side of the strait considerably greater than those in the balance of the strait. However, rather than accelerate through the strait, the floes decelerate as they enter the strait and continue decelerating on the north side of the strait. This deceleration appears to result from obstruction to ice movement on the north side of the strait by relatively compact pack ice there.

Fig 18



174° 30' 173° 30' 172° 30' 171° 30' 170° 30' 169 30' 168° 30' 167° 30' 166° 30' 165° 30' 164° 30'
67°
30'
66°
30'
65°
30'
64°
30'
63°
30'
62°
APRIL 77

Figure. 19

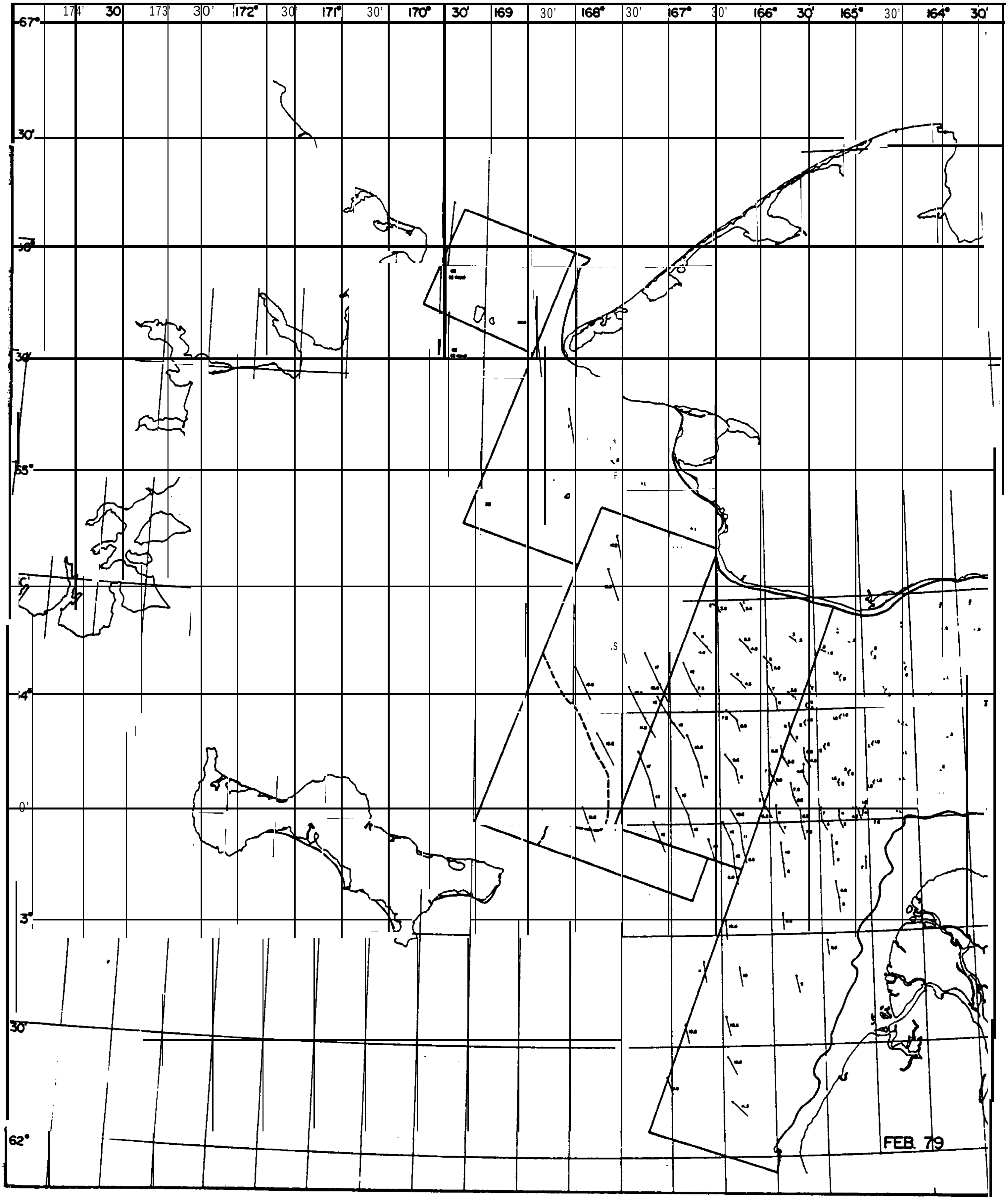
February 17-23 1979

The data presented here were obtained over a span of five one-day periods which overlapped providing several two-day displacements and in one case because the ice movement had a westward component, a 3-day displacement. During this time ice motion in the eastern Bering Sea was north-trending, while ice motions in western Norton Sound were very small, In the eastern Beaufort Sea, ice displacements generally increase from south to north and from shore into the ocean. (The south-to-north trend appears to be partly a day-to-day increase in displacement and partly a spatial distribution of velocities.

In the vicinity of Bering Strait, daily displacements are as large as 43 km/day. One floe was tracked over a tota? displacement of 118 km in three days from a location south of King Island to a location north of the Strait.

During this push of ice to the north, ice displacements within western Norton Sound were very small and tended to participate in a clockwise gyre as predicted by Stringer and Hufford (1982) during times of northwestward movment of Bering Sea ice.

Fig 19



174'
30
173'
30'
172°
30'
171°
30'
170°
30'
169
30'
168°
30'
167°
30'
166°
30'
165°
30'
164°
30'
67°
30'
66°
30'
65°
64°
0'
3°
30'
62°
FEB. 79

Acknowledgements

This study was funded wholly by the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration, as part of the Outer Continental Shelf Environmental Assessment program.

REFERENCES

Colvocoresses, A.P. and McEwen R.B., 1973: EROS Cartographic Progress. Photogrammetric Engineer, Volume XXXIX, 13:1303-09.

Martin, S. and Bauer, J., 1980: Bering Sea Ice-Edge Phenomena. In Hood, D.W., and Calder, J.A. (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. I. Seattle: University of Washington Press, 189-211.

Martin, S.: Private Communication. Department of Oceanography, WB-10, University of Washington, Seatte, Washington, 98195.

Muench, R.D. and Ahlnas, K., 1976: Ice Movement & Distribution in the Bering Sea from March to June 1974. Journal of Geophysical Research, 81:4467-4476.

Pease, C. J., 1980: Eastern Bering Sea Ice Processes. Monthly Weather Review, 108:2015-2023.

Ray, V. M. and Dupre, W. R., 1980: The Ice-dominated Regimen of Norton Sound and Adjacent Areas of the Bering Sea. In Hood, D.W., and Calder, J.A. (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. I. Seattle: University of Washington Press, 263-278.

Stringer, W. J. and Hufford, G.L., 1982: Interaction of Bering Sea and Norton Sound Pack Ice. Arctic and Alpine Research, 14: 149-156.